Energy Harvesting Active Networked Tags (EnHANTs)

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Energy Harvesting Active Networked Tags (*EnHANTs for short*) are small devices that can be attached to arbitrary objects that are traditionally not networked: books, cups, toys, keys, pens, produce, clothing etc. As society is transitioning from barcodes to RFIDs, we envision a future transition from RFIDs to EnHANTs that

- **energy harvest**: collect/store energy from ambient light, motion, temperature gradients, etc.
- **network**: communicate with one another and tag-friendly devices in a delay tolerant fashion.
- **are energy adaptive**: alter communications to satisfy energy constraints (not vice versa).
- **are thin, flexible tiny** (a few square cm at most).

EnHANTs are a disruptive technology that enables novel object tracking applications that are unavailable with conventional technologies that either consume too much energy to be implementable within the necessary size (e.g., Bluetooth, IEEE 802.15.4), or have no networking abilities (e.g., RFIDs) and require objects to be near to high powered readers.

1 Background/expertise

Our team's background enables a **comprehensive novel cross-layer design approach** using expertise in **networking, communications, low-power RF analog circuits, and energy-harvesting materials and devices.** Such a team is needed to accomplish the orders-of-magnitude efficiency improvements needed to make EnHANTs a reality. The hardware/device research needs a clear direction of how the communications and networking can adapt to changes in hardware capabilities *as designs are proposed and considered*. Similarly, the communications and networking teams needs a solid understanding of the underlying new hardware's constraints and capabilities to design models, algorithms and protocols that match these specific capabilities.

2 Vision

Our cross-layer research program[1] *is developing a networking, communication and implementation platform to realize EnHANTs at such a low cost that they can be attached to all objects around us.* The networking and communication platform will guarantee a self organizing network that we can interrogate for the current or past presence of objects. Our overall goal is to create a technology to organize the world's physical objects, implementing applications such as:

- **Lost Item and Disaster Recovery**: networked items can be tracked down (e.g., "where are my keys, eyeglasses?") or can in fact initiate alerts (e.g., "keys not near wallet", "milk out of refrigerator for 10 minutes"), individuals in a disaster can be localized.

- **Emergency Alerts**: High priority searches can be globally initiated through a combination of wide area and EnHANT networks, e.g., implementation of an Amber alert for a child's clothing/jewelry.

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- **Temporal and Spatial Proximity Information**: During an outbreak that leads to a product recall, more precise tracking of which objects clustered together over time. Specific localization methods between tags can also be implemented (folders in a filing cabinet identifying a sorting order, library books in stacks, perishable food in a refrigerator).

EnHANTs must be small and remain operational for extended periods of time (months to years). Considering that light harvesting technologies can yield available electrical power levels of about 1μW/cm^2 indoors [3], and wireless communications in the 3-5GHz frequency range need planar printed antennas [2] of about 2cm by 3cm, then less than **1 nJ/bit** can be expended for small tag sizes – much less energy than conventional standards such as Bluetooth and Zigbee (802.15.4) needing 220nJ/bit [1] or more. Fortunately, the needs of the EnHANTs' applications are very different from traditional wireless communication needs:

- **Small message sizes (a few bytes):** messages only carry information about IDs, and perhaps a timestamp.
- **Low throughput rates (no more than 1 Kb/s)** and **High Delay Tolerance (seconds to minutes)**: Aside from rare emergency scenarios (e.g., Amber Alert, building collapse), tags should only communicate when they remain within one another's proximity.
- **Low transmission range (a few feet)**: tags are only expected to communicate when in very close proximity to one another. This helps significantly reduce our signal energy requirements.

3 Evidence of Major Advance

The **transformative nature of our research** will enable *practical wireless networked communication at significantly lower power and extend the reach of networking to every day objects that cannot be networked today.*

Our plan is to co-design and analyze the hardware and protocols for tags and produce a proof-of-principle tag prototype that utilizes the novel hardware and protocols. Our research contains both a significant analytical and experimental component, culminating in a prototype testbed consisting of a few dozen tags that, when placed within near proximity of one another, are able to exchange their unique IDs, and can be queried remotely for the search of a particular tag ID.

References

[1] J.W. Hui and D.E. Culler. Extending IP to Low-Power, Wireless Personal Area Networks. *IEEE Internet Computing*, 12(4):37–45, 2008.

[2] Y. Kim and D.-H. Kwon. CPW-fed planar ultra wideband antenna having a frequency band notch function. *Electronics Letters*, 40(7):403–405, April 2004.

[3] J. A. Paradiso and T. Starner. Energy scavenging for mobile and wireless electronics. *IEEE Pervasive Computing*, 4(1):18–27, 2005.